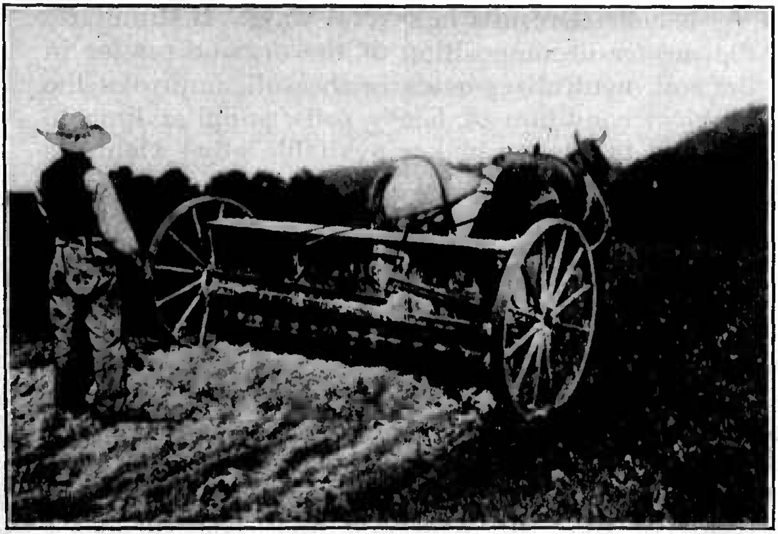
THE PRINCIPLES OF THE LIMING OF SOILS

EDMUND C. SHOREY
Scientist in Charge of Chemical Investigations



FARMERS' BULLETIN 921
UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Soils
MILTON WHITNEY, Chief

Washington, D. C. March, 1918

Show this bulletin to a neighbor. Additional copies may be obtained free from the Division of Publications, United States Department of Agriculture

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1918

THE APPLICATION of lime to soils brings about beneficial results in several ways. It stimulates the proper decomposition of the organic matter in the soil, neutralizes acids in the soil, improves the physical condition of heavy soils, supplies lime to growing plants, or makes available other elements in the soil.

The great majority of the soils of the East, South, and portions of the Central West are deficient in lime and will respond in increased yields to applications of lime.

In the following pages information is presented regarding the materials used in liming, their preparation and use, as well as a discussion of the chemical changes brought about in the soil by lime, so far as they are known. The relative merits of different forms of lime are discussed and data furnished whereby the value of any particular form of lime for agricultural purposes may be determined approximately.

The bulletin has been prepared primarily from the point of view of materials used in liming and of the principles involved in their use.

THE PRINCIPLES OF THE LIMING OF SOILS.

CONTENTS.

INTRODUCTION.

THE PRACTICE of applying lime to soils for the purpose of increasing crop yields has been more or less common in many parts of this country since its first settlement, has been followed in many parts of Europe for centuries, and dates back more than 3,000 years.

The term liming as generally used means the application to the soil of the element known to chemists as calcium in one of two forms—either calcium carbonate, more commonly known as carbonate of lime, or calcium oxide, the ordinary burned lime of commerce. Carbonate of magnesium mixed with carbonate of lime, as in dolomitic or magnesian limestone, and the mixed oxides resulting from burning such limestones are included also under the term lime.

MATERIALS USED IN LIMING.

CARBONATE OF LIME.

Carbonate of lime occurs in nature in several forms, of which ordinary limestone and marl are the most common. Marble, chalk, coral, and oyster and clam shells are forms not so widely distributed. All of these forms when properly prepared are suitable for agricultural use.

Limestone.—Limestone is one of the most common of rock formations; and although its appearance probably is familiar to everyone, some other rocks are so similar that they are sometimes mistaken for it. Limestone may vary in color from a very light gray to almost black, with shades of red or brown in some cases, and may vary considerably in hardness. It may be distinguished from other rocks of similar appearance by the fact that it effervesces—gives off bubbles of gas—when a drop of dilute acid (muriatic acid) is applied to it.

Limestone is prepared for direct agricultural use by grinding or pulverizing, and when so prepared is marketed as ground limestone,

pulverized limestone, or sometimes under proprietary or trade names that do not indicate its composition. In chemical composition limestone is essentially carbonate of lime, but it varies in its content of this principal constituent from 95 per cent or more to less than 80 per cent, and occasionally as low as 60 per cent. The average content of carbonate of lime probably is about 83 per cent. The impurities present are small quantities of a large number of minerals, none of which can be considered of any agricultural importance except as so much inert material that must be hauled and handled when a limestone of low grade is used. Except on land in the immediate vicinity of the limestone deposit, limestone containing less than 80 to 85 per cent of carbonate of lime is not generally used.

Magnesian limestone.—The term magnesian limestone is applied to one that contains both carbonate of lime and carbonate of magnesia. The term "dolomitic limestone" also is applied to the same material. In appearance it often can not be distinguished from ordinary limestone. Usually it does not effervesce on the application of dilute acid at ordinary temperature, but does so on warming. The value of this limestone for agricultural use is usually considered as equal to that of ordinary limestone, that is, one containing 85 per cent of lime and magnesia carbonates would be equal in value to an ordinary limestone containing 85 per cent of carbonate of lime.

Marl.—Marl, as the term is most commonly used, is a form of carbonate of lime that has been deposited from water. It occurs frequently as a deposit under other material or in the beds of streams or lakes. It is usually in a more or less finely divided condition, but sometimes the material has become more or less cemented and requires grinding before it can be used. Marl is more variable in its content of carbonate of lime than is limestone, and the impurities present are usually clay or silty material. In some sections the term "marl" is applied to greensand material containing glauconite, a mineral which contains potash. The content of carbonate of lime in greensand usually is rather low. Marl sometimes has an advantage over limestone where carbonate of lime is to be used in that it may not require grinding, or at most may require only a mashing of the more or less friable lumps and is naturally in a finely divided condition. Except for this its value as compared with ground limestone should be judged by its content of carbonate of lime. In some localities are found deposits of shells partially disintegrated and more or less cemented together. Such deposits often are called marl or shell marl. Frequently they are hard and require grinding before they are suitable for agricultural use.

Marble.—Marble is the same in chemical composition as high-grade limestone. It is too valuable for other purposes to be available for

agricultural use, but sometimes small quantities of marble waste are available for this purpose.

Coral.—Coral is the skeleton remains of marine organisms and is essentially carbonate of lime. Where coral deposits have become elevated above sea level, the surface material where exposed may become weathered so that it is soft and friable, much like marl in character. Below the surface, however, it usually is hard and compact and must be ground. Supplies of coral are of limited extent in the United States, being confined to portions of Florida and Hawaii. Where available it may be considered of the same value as limestone or marl of the same content of carbonate of lime. In the vicinity of coral formations beach sands frequently occur that are made up of coral fragments mixed with small shells. This so-called coral sand is variable in its content of carbonate of lime, but is of value as a source of material for liming in proportion to this content.

Oyster and clam shells.—Oyster shells and clam shells when cleaned of adhering dirt and organic material contain 90 to 95 per cent of carbonate of lime. When coarsely ground they are extensively used for poultry feed, in the preparation of which the finer material is sometimes sifted out and offered for agricultural use. Such material may contain all the sand and dirt that accompanied the shells. Clean shells when burned or when finely ground constitute a very valuable, although limited, supply of lime for agricultural purposes, and when ground to the same degree of fineness they may be considered as of the same agricultural value as other forms having the same content of carbonate of lime.

Chalk.—Chalk is material that has been deposited in much the same way that marl has been. It is very free from impurities, being in most cases nearly pure carbonate of lime. Chalk has been used somewhat extensively in agriculture in some countries, but deposits in this country are of insufficient extent to warrant considering it a source of material for liming. Deposits in this country that usually are known as chalk more properly should be called marl.

Waste lime.—In many industries there are waste products containing oxide of lime or lime carbonate that frequently can be obtained and used locally at small cost. Such products are the lime from gas works, paper mills, tanneries, water-softening processes, spent calcium carbide, and slags from iron or other works. These may contain other compounds that might be injurious to vegetation and their freedom from these should be assured before they are used. Such materials usually contain excess of moisture and can not profitably be shipped without previous drying, and their value for agricultural purposes depends not only on their content of lime oxide or carbonate but also on their freedom from injurious compounds.

OXIDE OF LIME.

Oxide of lime is marketed in several forms, all of which are derived from some form of carbonate of lime by heating or burning. By this process carbonic acid is driven off, leaving the oxide. Any of the forms of carbonate mentioned can be used for the manufacture of the oxide, but as a matter of fact, except for a small quantity obtained by burning oyster shells, all calcium oxide is made from limestone. The purity of the product obtained depends on the purity of the limestone used, since nothing is removed by the burning except the carbonic-acid gas.

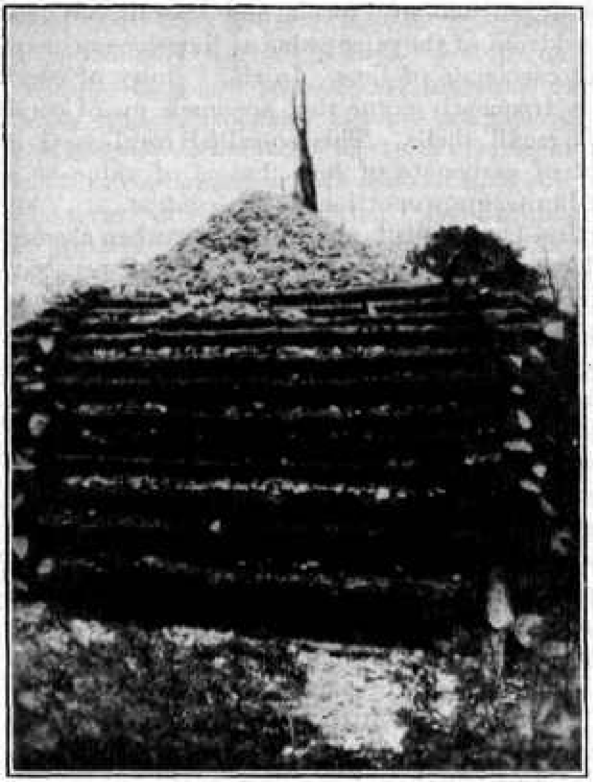


FIG. 1.—A kiln for burning oyster shells.

Burned lime.—The term "burned lime" is applied to the ordinary lime prepared by burning limestone in lumps. The terms "quicklime," "caustic lime," "lump lime," and "builder's lime" are also applied to this material. In burning the limestone retains to a large extent the lump form in which it was placed in the kiln and the product is marketed in that form in bulk or in barrels.

Ground lime.—The term "ground lime" is applied to lump or burned lime that has been finely ground but has had no other treatment.

Hydrated lime.—When oxide of lime is treated with water, chemical combination takes place; heat is generated and the lump falls to a powder quite as dry in appearance as the original oxide, if no more than the proper quantity of water has been used. This process is called slaking and the product is known as slaked lime, calcium-hydroxide, lime hydroxide, or hydrated lime. The term "hydrated lime" is the accepted trade name for slaked lime prepared by lime

manufacturers. The product is finely divided and is necessarily of high grade because in the process all unburned lumps (core) and slag or overburned lumps are rejected.

Agricultural lime.—The term "agricultural lime" was originally applied to burned or lump lime from which the unburned lumps or core and overburned lumps had not been taken out, as must be done when burned lime is offered for the building trade or chemical industries. Such lime is frequently designated run-of-kiln lime. Recently there has been a tendency to apply the term "agricultural lime" to any form of lime used for agricultural purposes, so that at present the term has no special significance.

LIME IN SOILS.

Practically all crop-producing plants require that lime in some form be present in the soils in which they grow. As a matter of fact, all soils contain some lime, and it has been assumed pretty generally that soils usually contain all the lime that is necessary for plant growth. This lime occurs in the soil in a number of different forms or combinations. In addition to the carbonate mentioned, it may be present as the sulphate, known commonly as gypsum, or as different forms of complex compounds known as silicates. These lime silicates make up a large part of some of the rocks from which soils are formed, are very slightly soluble, and furnish lime to the soil solution by slow decomposition. Lime also occurs in many soils combined with the organic constituents known as humus. In this form it usually is slightly soluble, and lime thus combined is held in the soil in a form to be utilized by microorganisms.

Carbonate of lime is much more soluble in the soil water than are the lime silicates and, when present, is leached from the soil first and lost in the drainage water. The soils of the Eastern, Southern, and portions of the Central States contain only traces of carbonate of lime, and on the basis of content of carbonate of lime the soils of the United States may be divided roughly into two geographic divisions. If a line beginning at the center of the northern boundary of Minnesota be drawn south through that State, curving west and cutting off the northwest corner of Iowa, thence west to central Nebraska, south through Kansas, Oklahoma, and Texas to near the Mexican border on the Gulf, it may be said that generally the soils east of this line, except in river bottoms and a few relatively inextensive upland areas, contain but small quantities (less than half of 1 per cent) of carbonate of lime. Such soils do not effervesce on the addition of dilute acid. West of this line the soils frequently, and the subsoils always, contain appreciable quantities of carbonate of lime, except at high elevations and on the Pacific coast.

EFFECTS OF LIMING.

If soils generally contain sufficient lime for the growth of crops, the question naturally arises, Why apply lime? The answer to this is that lime in the form either of carbonate or of oxide aids in bringing about changes in soils that make them more suitable for the growth of crops. It produces effects quite apart from supplying lime to the plant. These effects may be discussed under several heads.

Liming corrects soil acidity.—All soils contain some organic matter, the remains of previous crops or similar material that has been added to them. This organic matter decays in the soil and among the products of this decay organic acids are present. In soils in a condition of good cultivation and well drained these acids may combine with mineral constituents of the soil, their acid nature being thereby neutralized. On the other hand, they may be prevented from accumulating to an injurious extent. This latter result may be effected by drainage or by changes promoted by free access of air. When this neutralization or change does not take place and acids accumulate, the soil becomes acid, or sour. It is probable that in all cases where soils are acid because of the presence of organic acids, the soils contain excess of organic material, as in the case of mucks or peats, or the upper layer of woodland or some virgin soils. When organic acids are present in soils low in organic matter, usually there is poor drainage.

In addition to acids arising from the decay of organic matter in the soil, many soils probably contain compounds of an acid nature derived from complex silicates that form a large part of the rocks from which soils are formed. These compounds use up lime in the same way that ordinary acids do, that is, they require a certain amount of lime to be added to the soil before a neutral or alkaline reaction is brought about. Under certain conditions strong mineral acids such as sulphuric acid may be generated in soils from minerals such as pyrite, but instances where such acids have been proved to be present in quantity sufficient to bring about strongly acid conditions are not common.

Both the forms of lime used in liming have the power to neutralize acids, oxide of lime by combining directly with the acid, thereby forming a neutral, or nonacid, and usually harmless compound, and carbonate of lime by entering into a reaction with the acid whereby the carbonic-acid gas is liberated and the same neutral compound formed as when the oxide is used.

The term lime requirement is used to express the quantity of lime that must be added to a soil so that its acid character will disappear. A number of methods have been proposed for determining this, all of them requiring laboratory equipment and none of them giving any-

thing but an approximate figure. This lime requirement usually is stated in pounds of lime oxide required for an acre of soil to a depth of 6 inches or some other stated depth.

Liming improves the physical condition of heavy, compacted soils.—In heavy soils, those containing large proportions of clay or silt, there is a tendency under certain conditions for the fine soil particles to become associated so closely that the soil becomes compacted, preventing free access of air and water, a condition unfavorable to plant growth. Under other conditions the fine particles, instead of behaving in this way, tend to gather in small groups or floccules, each group behaving as a large particle. When this takes place the soil particles are said to have flocculated and the soil has a crumb structure. Every farmer knows this crumbly condition of the soil when he sees it and knows that in tilling such soils it is desirable to get the soil into that condition. Liming has been found to favor this and the consequent better aeration and drainage following the liming of heavy, compacted soils are among the important effects of liming. In some cases lime exerts a binding effect on sandy soils, preventing blowing or erosion.

Liming stimulates the proper decomposition of organic matter in the soil.—One of the advantages of an adequate supply of organic matter in a soil, or of supplying this material by means of manure, fertilizers, or cover crops, is that in decomposing it furnishes the food necessary for the growth of the bacteria that render nitrogen in the soil available to plants. In other words, it is through the decomposition of organic matter in the soil that crops can grow. A soil without organic matter or with organic matter that could not be decomposed, if that were possible, would be worthless for crop production.

Lime in the form of oxide or carbonate not only stimulates the decomposition of organic matter in the soil but brings about conditions favorable to a decomposition that will be most beneficial to growing crops.

The microorganisms that render the nitrogen of organic material available to plants and the nitrogen-fixing organisms that increase the store of nitrogen in the soil are benefited by liming. In other words, liming properly practiced tends to bring about the most economic utilization of the organic matter naturally in a soil and directs the decomposition of organic matter added to it so that its value is most fully realized.

Liming may increase the availability of other minerals in the soil.—It has been somewhat generally assumed and taught that one of the beneficial effects resulting from liming is due to the fact that applications of lime rendered other minerals, especially those con-

taining potash, more soluble and therefore available to the growing crop. Recent investigations, however, indicate that while this effect of liming may be somewhat general, it is not true to the same extent for all soils and that in some soils this effect is very slight.

Liming may furnish needed lime to plants.—As has been stated, the assumption is general that all soils contain sufficient lime to satisfy the needs of the plant for lime in building up its tissues. There is, however, considerable evidence indicating that this may not always be the case and some of the beneficial results following liming may be due to the direct furnishing of needed lime to the plant. Soils are not uncommon in which the content of lime in any form is less than the content of any other common element, and it is not unreasonable to suppose that in growing on such soils crops like clover or alfalfa, crops that are known to take large quantities of lime from the soil, the benefits from liming may be due, in part at least, to the direct supply of lime.

General discussion of the effects of liming.—Of the several effects of liming just mentioned, the correction of soil acidity is probably the one most commonly thought or spoken of, the others being considered secondary. Consideration, however, of the relative weights of these effects of liming will lead to the conclusion that the correction of acidity is not the most important. Although there are large areas of uncultivated soil that are decidedly acid, they are for the most part areas that are in need of drainage and are acid for that reason. Soils that are decidedly acid are not nearly so common in cultivation as is somewhat generally supposed. Peats and muck soil, where not associated with marl deposits, are often decidedly acid, and soils of all textures where drainage conditions are bad also may be decidedly acid, but the great majority of soils that are almost devoid of carbonate of lime and that respond in crop yields to liming are not strongly acid when judged by any standard in use for that purpose.

As has been stated, the presence of decomposable organic matter is essential to a fertile soil, and organic matter is added to soils in the form of fertilizers, manure, and cover crops for the purpose of being decomposed, and no fact is more clearly demonstrated in connection with liming than that the addition of lime to a soil promotes this decomposition or tends to direct it in a way that is favorable to the growth of crop plants. This is an effect that takes place in all soils, and it would seem therefore that because this effect of liming is the most general it is the most important.

The effect of liming on the physical condition of the soil is observable where the physical condition is in need of improvement, that is, it is one that will be observed chiefly on heavy, compacted soils.

The effect of lime in liberating other minerals in the soil and of supplying needed lime to the plant are effects that apparently are limited also in their operation to certain types of soil.

The relative importance of the different effects of liming may be stated as follows: The effect on the decomposition of organic matter in the soil is most general and probably of first importance. The correction of soil acidity comes next in importance, and this importance will increase in proportion to the increase in acreage of sour or acid soils under cultivation. The effect of liming on the physical condition of the soil may be considered perhaps of somewhat less importance than the correction of soil acidity. The effect of lime in liberating other minerals and of supplying lime direct to the plant may be considered of minor importance, although there may be cases where these effects are of first importance.

It is evident that several or all of the effects of liming may operate in the same soil at the same time, and it is likely that in few cases are the benefits resulting from liming due to one effect alone.

FARM PRACTICE OF LIMING.

In attempting to increase his crop yields by liming the farmer naturally seeks to accomplish this with the least expense for labor and material, and he also should keep in mind the necessity of maintaining or increasing the fertility of his soil for future crops.

The factors to be considered in the practice of liming may be discussed under several heads.

THE SOIL.

The soil, either as nature made it or as modified by previous cultivation, for purposes of immediate utilization, the farmer must take as he finds it.

As was brought out in the discussion of the effects of liming, all soils that need lime do not need it for the same reason. As the result of liming, one soil may be benefited chiefly through the neutralization of its acidity and another through the improvement of its physical condition, but in nearly all soils the decomposition of the organic matter will be hastened and in some cases all effects will operate at the same time.

The kind of soil and the result sought to be accomplished will determine in part the practice to be followed. Peats, muck soils, and nearly all soils devoid of carbonate of lime and having poor drainage are likely to be decidedly acid, and the liming of these should be practiced with a view to remedying that condition. This practice frequently will call for a large application of lime.

A heavy soil that has become compacted so that drainage and circulation of air are hindered should be limed for the correction of that condition and for that purpose comparatively smaller applications will be effective if the soil is not at the same time acid. It may be that the topsoil is in fairly good physical condition but that the drainage is bad because of the presence of a hardpan or impervious layer at lower depths. Surface applications of lime, which tend to modify the character of the topsoil only, will remedy such conditions very slowly, if at all. In some such cases merely breaking through the impervious layer will be sufficient, but in others drainage must be provided by the usual means of ditching or tiling.

In stimulating the decomposition of organic matter it may be assumed that any application of lime, however small, will be of service in this direction; but here there comes into consideration one of the most important points in connection with liming. The organic matter in a soil is of service chiefly because it decomposes, and lime aids in decomposing it; but many light sandy soils contain very little organic matter, and to stimulate the decomposition of this without taking steps to replace, or if possible to increase the supply by applications of manure or plowing in green crops would be disastrous for future crops.

One of the first rules to be observed in liming is that lime in any form should not be applied to soils deficient in organic matter, especially in warm humid climates, without taking steps to put organic matter into the soil to keep up, or if possible increase, the supply of this essential ingredient.

THE CROP.

In considering the crop in its relation to liming it must be borne in mind that, except for some general relations true for a particular crop on almost all soils, the nature of the soil will determine whether or not a particular crop requires that lime should be added to the soil for best production.

Of first consideration in this connection is the fact that leguminous plants usually require a plentiful supply of lime; or, in other words, it is generally true that legumes take large quantities of lime from the soil. Further, many legumes are sensitive to acid soil conditions and do not grow well or frequently not at all where such acid conditions exist. This is particularly true of alfalfa and red clover and perhaps to a less degree of sweet clover and vetch. On the other hand, cowpeas and soy beans usually do not respond to liming, and white clover grows well on acid soils.

Corn is usually considered to be tolerant of acid conditions and such grasses as redtop, Bermuda grass, and lespedeza grow well on acid soils. Bog plants, such as blueberries and cranberries, require

an acid soil and such fruits as strawberries and raspberries apparently are not benefited by applications of lime.

The great majority of garden and truck crops and cereals usually are benefited by liming, but when it is recognized that different soils require lime frequently for different reasons, one for correction of acidity, another for improvement of the drainage or to supply lack of lime, it is clear that a crop that responds to liming on one soil may not do so on another. This leads to the advice that farmers should experiment with their own soils to determine the response to liming with different crops. This advice applies also to fertilizer practice, crop rotation, varieties grown, and in fact to all the operations connected with the growing of crops, and only when farmers do this and make use of the information so gained can the best results be expected.

USE OF LIMING MATERIALS.

Under the heading "materials" it has been stated that the material used in liming is either carbonate of lime or oxide of lime, and that there are several kinds of these two forms. It sometimes happens that because of local market or other conditions a farmer is limited to one form of lime—that is, because of the expense of freight, etc., other forms are prohibitive in cost—but usually the farmer has a choice of several kinds or brands.

Where this is the case the choice may be said to be first between carbonate of lime and the oxide, and this makes necessary some discussion of the way these two forms of lime behave in the soil.

CARBONATE OF LIME.

Carbonate of lime is almost insoluble in pure water, but water holding carbonic-acid gas in solution, as does all soil moisture, dissolves appreciable quantities, depending on the quantity of carbonic-acid gas in solution. It is due to this solubility in the soil solution that carbonate of lime in the form of limestone is gradually leached from soils.

If the soil water contains a free acid in solution, as may be the case in some instances, this acid might be neutralized by the soil solution coming in contact with solid particles of carbonate of lime, an effect that might be produced without the carbonate of lime being previously dissolved. Probably, however, in most cases acids or acid compounds in soils are so slightly soluble that they are neutralized by the carbonate of lime in solution coming in contact with the more difficultly soluble acid.

Regarding the action of carbonate of lime in stimulating the decomposition of organic matter, only the general principles involved are known or understood. It is known that the growth of many

microorganisms active in decomposing the organic matter of soils is hindered by an accumulation of free acid, therefore the stimulation of the decomposition in many cases doubtless is due indirectly to the neutralization of acid, making the soil thereby more favorable for the growth of microorganisms. On the other hand, however, many forms of decomposition may advance to a considerable degree under acid conditions. In other cases the favorable action may be due simply to the fact that the new compounds formed by the combination of lime with neutral organic compounds are in a form available for plants or microorganisms.

The effects of lime in flocculating soil particles and making the conditions more favorable for the circulation of air and water, as well as the effect of making soluble other minerals, so far as they are understood, depend on the lime being in solution in the soil moisture.

Except, then, for cases such as the neutralization of an acid in solution by coming in contact with solid particles of carbonate of lime, the beneficial effects of carbonate of lime when added to a soil follow only after this lime has gone into solution in the soil moisture. This being the case, the value of any carbonate of lime, so far as its chemical activity in the soil is concerned, depends on its content of carbonate and on its solubility.

The rapidity with which any material not readily soluble in water is dissolved depends on how finely it is powdered or pulverized—that is, on how much surface is exposed to the action of the water. This is true of carbonate of lime; and though there may be slight differences in solubility due to kind of material and the nature of impurities present, for all practical purposes the rate of solution of one kind of carbonate of lime may be assumed to be the same as that of any other kind of the same degree of fineness.

In addition to its effect on rate of solution fineness of grinding of carbonate of lime makes it possible for the material to be more thoroughly distributed throughout the soil so that the solution formed comes in contact with all of the soil in a shorter time.

The value of carbonate of lime, therefore, so far as its immediate activity in the soil is concerned, is dependent on the extent to which it is powdered or pulverized, for it is only through solution that the lime can be distributed and reach all parts of the soil.

OXIDE OF LIME.

In discussing oxide of lime it was pointed out that any form of carbonate would furnish the oxide on burning. The oxide may differ somewhat according to the material from which it was made and may differ as to preparation, whether lump or ground, and whether slaked (hydrated) or unslaked. Some consideration must be given, then, in this connection as in the case of carbonate, to the way in which the oxide behaves in the soil.

Calcium oxide or oxide of lime has a great affinity for water. When it is brought in contact with water chemical action takes place, heat is generated, and the lump of lime falls to a dry powder or forms a semifluid milky mass, according to the quantity of water used.

In this reaction (slaking) chemical combination between this oxide and the water takes place. The same action takes place, but more slowly, when the oxide is exposed for a time to the air, simply by the moisture of the air being taken up, but in this case the process is extended over so long a period of time that the heat generated is not noticeable. This process, called air slaking, takes place even in fairly tight containers, such as barrels.

The oxide of lime after slaking is in the form known as calcium or lime hydroxide, and usually when oxide of lime is used in agriculture it is slaked and changed to the hydroxide form before applying to the land; if not, this change very soon takes place by combination with the moisture of the soil.

Lime hydroxide is many times more soluble in pure water than is carbonate of lime, or even than carbonate of lime is in water charged with carbonic-acid gas as soil moisture is. The first result, then, when the hydroxide comes in contact with water is solution. When lime hydroxide is applied to a moist soil solution also takes place and this solution tends to be diffused throughout the soil. Theoretically the fate of this calcium hydroxide in solution in the soil moisture would be its conversion into calcium carbonate through interaction with the carbonic acid also held in solution. The extent to which this reaction would go would depend on the relative proportions of the two reacting compounds present. If much calcium carbonate were formed in this way it would be thrown out of solution and finally react in the soil in the same way as finely divided carbonate added to the soil directly.

In some cases, no doubt, there is direct union of the lime hydroxide with organic compounds without the previous formation of carbonate, but in a general way the chemical processes by which beneficial effects on crops are produced must be the same whether the oxide or carbonate be used.

There are two conditions in which the use of lime oxide may bring about somewhat different results from those produced by the carbonate. If the oxide, either ground or in lump form, should be applied to the soil without first slaking, contact with moist soil would at once bring this slaking about, considerable heat would be generated and chemical changes brought about in the soil at points where the slaking took place might be quite different from those following applications of lime already slaked.

It is due chiefly to the generation of heat and abstraction of water accompanying slaking that the popular idea regarding the caustic or

burning character of burned or quicklime is due. As a matter of fact, after slaking has taken place and normal temperature been reached, the resulting hydroxide is at ordinary temperatures very mild in its chemical activity and harmless in its relation to organic material.

Another condition where lime hydroxide might behave in a manner different from the carbonate is met with in the case of light sandy soils containing little organic matter. Here the amount of carbonic-acid gas in the soil water is apt to be small and the water-holding power of such soil is low. In consequence, if slaked lime had been added, the hydroxide would not be changed rapidly into carbonate or in the absence of organic matter and finely divided mineral matter little opportunity would be offered for other chemical combination and there might be a rather free circulation of a saturated solution of lime hydroxide in the soil. This would result in much of the lime being leached away in place of being changed to carbonate and held in the soil to bring about the slow changes and beneficial results desired. In addition the saturated solution of lime hydroxide has some dissolving action on organic constituents, and this might result in a loss of the already deficient organic matter by solution and leaching.

It was pointed out in connection with carbonate of lime that the relative values of different forms depend on the content of carbonate and the fineness of the particles. A similar statement holds for lime oxide, but as a matter of fact all forms when slaked are extremely fine and probably of equal value in that respect, so that the value of different forms of lime oxide depends on their purity or content of lime oxide.

The farmer has, then, in the choice of material, the following facts to consider, so far as the efficiency of lime in the soil is concerned. All forms of ground or pulverized carbonate of lime are approximately alike if their purity is the same and they are ground to the same degree of fineness. If of the same purity their efficiency depends on the fineness of grinding, the finer being the more active; and vice versa, if of the same fineness, their efficiency will be in proportion to the content of carbonate of lime, or carbonate of lime and magnesia where magnesian limestone is used.

In the case of burned lime all forms when slaked are approximately of the same degree of fineness and their value depends on the purity or content of oxide of lime or lime and magnesia.

LIME OXIDE VERSUS LIME CARBONATE.

It has been pointed out that the value of lime oxide represented by burned lime depends upon its purity, and that for immediate effect the value of carbonate of lime represented by ground or pulverized limestone depends upon its purity and the fineness of grinding. It is plain, then, so far as immediate efficiency in the soil is concerned,

that the value of the latter, as compared to the former, depends on the equivalent value of carbonate when calculated to oxide and how nearly its fineness approaches the fineness of slaked lime; in other words, What is the equivalent lime oxide calculated from the lime carbonate, and how much fine material that may be considered immediately available is there in the pulverized limestone?

The relative value of lime carbonate to oxide of lime is in the ratio of 56 to 100; or, in other words, 100 pounds of carbonate will produce 56 pounds of oxide on burning. Stated in still another way, 100 pounds of carbonate must be used to produce the same chemical effect as 56 pounds of oxide.

It is not possible within the limits of reasonable cost to grind limestone so that it is all as fine or even nearly as fine as slaked lime, and this has led to proposed standards or specifications regarding this feature.

In general terms it may be stated that the finer limestone or similar material is ground the more it will cost, and the finer it is ground the more quickly soluble and effective it will be in the soil. Naturally, however, there is a point where added expense for fine grinding is not warranted, because the increased crop production does not offset the increased cost of material. Results from field tests regarding the efficiency of limestone of different degrees of fineness, while naturally varying considerably as influenced by differences in soil, crop, and climate, all agree in support of the contention that some degree of fineness is necessary for immediate effect.

It may safely be assumed, therefore, that in the case of ground or pulverized limestone it is only the material of certain fineness that is immediately available and is comparable in value with the fine material obtained on slaking burned lime, and for immediate results fine material is all that should be considered in computing the relative values of such products.

Coarse material, though not immediately available, naturally is of some value, is slowly dissolved, and has its effect on the soil; but this naturally varies with varying conditions.

Though suggestions and ideas regarding the degree of fineness that should be required in pulverized limestone differ somewhat, probably a specification that a large percentage shall pass a 60-mesh sieve is the one most frequently made, and probably comes near striking the medium between very fine material at very high cost and coarse material produced cheaply.

As an example of how the comparative values of different materials may be calculated by means of this standard, a case may be assumed. Suppose that laboratory examination or experience with a similar soil indicates that a soil requires the immediate effect of 1,000 pounds

of oxide of lime or the equivalent quantity of the carbonate. Suppose, further, that the farmer is offered the following: Burned lime, 90 per cent oxide of lime, at $7.50 per ton; coarsely ground limestone, 85 per cent carbonate, 20 per cent passing a 60-mesh sieve, at $1.50 per ton; finely ground limestone, 85 per cent carbonate, 80 per cent passing a 60-mesh sieve, at $3.50 per ton. What are the relative values of these for immediate effect? Using the data given, the following result is obtained:

To furnish 1,000 pounds of oxide of lime would require 1,111 pounds of the burned lime, costing	$4.16
To furnish the equivalent of 1,000 pounds of oxide of line in the form of carbonate of lime would require 10,500 pounds of the coarsely ground limestone with 20 per cent passing a 60-mesh sieve, costing	7.87
To furnish the equivalent of 1,000 pounds of oxide of lime in the form of carbonate of lime would require 2,610 pounds of finely ground limestone, with 80 per cent passing a 60-mesh sieve, costing	4.56

In addition to the differences thus disclosed, it must further be noted that ten times as much coarsely ground limestone or two and a half times as much finely ground limestone is required, the freight and haulage of which must be considered. It should be noted in this connection that the prices quoted while in the proportion current in some localities are not suggested as proper values for such material but are assumed for the purpose of this calculation only. It should further be noted that this calculation is based on the assumption that in the case of ground limestone only material passing a 60-mesh sieve is immediately effective, and that immediate effect only is considered. The coarser material not considered in this calculation has some value for future crops.

In actual practice it is not possible to calculate relative values so closely as illustrated. In the first place, it is not possible to determine the needs of any particular soil for immediate lime effect more than approximately; the relative efficiency of carbonate of lime of different degrees of fineness necessarily varies with soil and climate, and generally the farmer does not know the composition of the material he uses, or at most only approximately.

The following facts should, however, be borne in mind in this connection: It requires approximately twice as much carbonate of lime to bring about the same chemical effect as oxide. A considerable portion of fine material in the ground or pulverized carbonate (limestone) is necessary for it to be immediately effective. If, then, a brand of ground limestone contains a fairly large percentage of fine material and contains 85 per cent or more of carbonate, it is probably worth half as much per ton as a high grade of burned lime and no more. Twice as much, however, must be used, and freight and haulage on the excess quantity must be considered in computing the cost.

Comparative tests of burned lime and ground limestone have been made at many of the agricultural experiment stations on a variety of crops, and while in some cases burned lime has been found to give the greater yield and in other cases the ground limestone, the general opinion is in agreement with that expressed in a bulletin from the Ohio Experiment Station: "In actual practice the experiments made by the Ohio Experiment Station have shown no practical superiority of one form of lime over the other provided the limestone has been so ground that 80 per cent of it will pass through a sieve having 100 meshes to the linear inch and provided of course that the two materials have been used on the basis of the actual calcium contained."

In the following table is shown the oxide-of-lime value of grades of carbonate (limestone) from 95 to 70 per cent and the oxide value of the material that will pass a 60-mesh sieve in the same grades:

Oxide-of-lime value of different grades of carbonate (limestone).

Carbonate of lime.	Total oxide of lime per ton.	Oxide of lime per ton where— 20 per cent passes 60-mesh sieve.	40 per cent passes 60-mesh sieve.	60 per cent passes 60-mesh sieve.	80 per cent passes 60-mesh sieve.
Per cent.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
95	1,064	213	425	638	851
90	1,008	202	403	605	806
85	952	190	391	571	761
80	896	179	358	538	716
75	840	168	336	504	672
70	784	157	313	470	627

Hydrated lime carries with it the water that has combined with the oxide, and consequently its oxide value is less than that of quicklime. The relation between the two is such that 100 pounds of hydrated lime contains approximately 75.7 pounds of oxide, and the relation between the three is as follows: 100 pounds of carbonate (limestone) are equal to 74 pounds of hydrate (slaked lime) or 56 pounds of oxide (burned lime); or, to put it in general terms, two parts of oxide are equal to three of hydrate or four of carbonate.

Under the discussion of materials mention was made of magnesian limestone, which is a mixture of lime and magnesia carbonates in varying proportions. Limestone of this kind and lime made from it by burning are somewhat generally offered for sale and used for agricultural purposes. This form of limestone does not react as readily with acids as does the ordinary—does not effervesce with a dilute acid at ordinary temperatures. The lime made from it does not slake as readily as that made from ordinary limestone, and probably acts more slowly in the soil.

In the past opinions differed considerably regarding the value of magnesian limestone or the lime made from it for agricultural pur-

poses, but the general opinion now seems to be that they are equal in value to the limestone or lime from ordinary limestone if of the same purity and degree of fineness.

The relation of magnesia carbonate to magnesia oxide is slightly different from that between lime carbonate and lime oxide, but the difference is so small that for all practical purposes the value of a magnesian limestone can be judged by its content of the two carbonates and a lime by its content of the two oxides. While 100 pounds of lime carbonate will yield 56 pounds of lime oxide, 100 pounds of magnesia carbonate will yield only 48 pounds of magnesia oxide, and 100 pounds of a mixture of equal parts of magnesium and calcium carbonates will yield 52 pounds of the two oxides. This fact gives ground magnesian limestone or the lime made from it a slightly greater neutralizing power than have the ordinary calcium limestone or lime.

OTHER FORMS OF LIME.

Other lime compounds than those discussed here are sometimes added to soils either directly or as components of fertilizers or other material.

Land plaster.—Land plaster, known also as gypsum, calcium sulphate, or sulphate of lime, has been somewhat extensively used in agriculture.

This lime compound is not active in any way in neutralizing soil acidity, and while it may bring about any of the other effects of liming, its action which frequently is referred to as a stimulating one is generally believed to be of benefit chiefly through the liberation of potash from soil minerals. Land plaster is also of value as an addition to manure and composts because it prevents the escape of ammonia from such material.

Acid phosphate.—Acid phosphate, also known as superphosphate, prepared by treating rock phosphate with sulphuric acid, contains both acid phosphate of lime and sulphate of lime. Acid phosphate is used both alone and as an ingredient of mixed fertilizers. For every 1 per cent of phosphoric acid in such material there is approximately 2 per cent of sulphate of lime and one-third of 1 per cent oxide of lime combined with phosphoric acid. Some of the effects of acid phosphate may be due in certain cases to the lime thus furnished, although this form has no power to neutralize soil acid conditions.

Ashes.—The ashes remaining after burning wood contain the mineral elements that were in the wood in the form of oxides or carbonates. Potassium carbonate and calcium carbonate or oxide are present in considerable and frequently large quantities and the ashes have a strong alkaline reaction, with the power to neutralize soil acidity in proportion to their content of oxides or carbonates.

The commercial value of wood ashes usually depends more on their content of potash than of lime, but nearly all contain enough lime to warrant their being considered among liming minerals.

Compost and manure.—All vegetable and animal material contains some lime, usually in combination with organic material or acids, and when it is added to soils this lime goes to replenish the store of lime in the soil. Lime from such sources is not effective in correcting soil acidity or improving the physical conditions of a soil.

Basic slag.—Basic slag, known also as Thomas slag, is a by-product of the iron industry and is used as a fertilizer. It is a phosphate of lime with an excess of lime. It has an alkaline reaction and when used on an acid soil tends to bring about a neutralization of

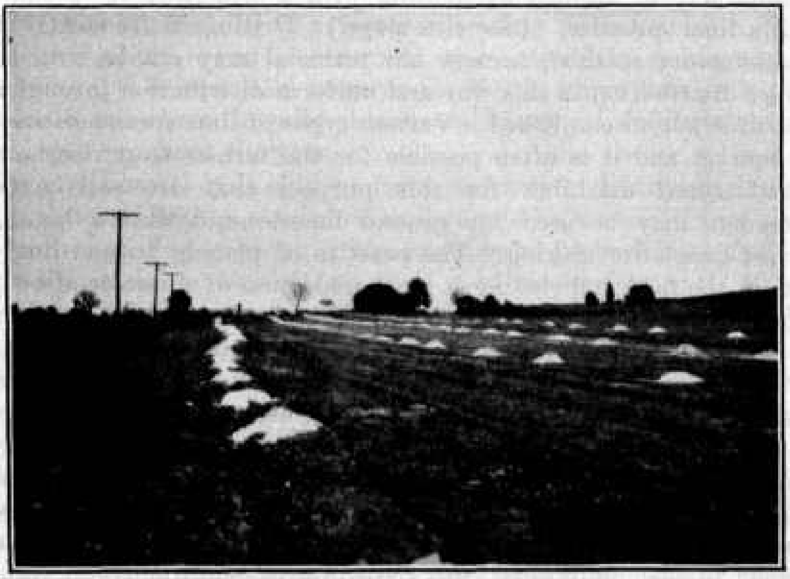


FIG. 2.—Burned lime on the field to be spread after slaking.

acid conditions to the extent of the excess of lime in it. Usually, however, it is not used in sufficient quantity to bring this about to more than a very limited degree.

OTHER FACTORS IN LIMING.

Time and method of application.—To a large extent the time and method of application are fixed by the kind of material, the nature of the soil and crop, and the farmer's convenience. So far as any possible injury is concerned, carbonate of lime in any of the several forms may be applied at any time. This material produces no injurious effect by direct contact with seeds or young plants, and does not tend to set ammonia free from stable manure.

Carbonate of lime should, however, not be mixed with or applied at the same time with acid phosphate, since such mixture or applica-

tion tends to bring about a change of the water-soluble phosphoric acid to an insoluble form, and any advantage in buying the more expensive acid phosphate is lost.

In considering the time of application of carbonate of lime, it must be remembered that it is slower in its action than burned lime, especially if not finely ground.

Oxide of lime, either in the form of burned lime or hydrated lime, requires somewhat more care in regard to time of application. It should not, especially if the unslaked form be used, be applied to the land so that it comes in contact with seeds or young plants. Like the carbonate, it should not be mixed with acid phosphate or applied at the same time, and should not be mixed with stable manure.

Lime may be applied by drilling with a seed drill or spreading with a lime spreader. (See title page.) Drilling is frequently not a satisfactory method, because the material may not be suited to proper distribution in this way and uniform distribution throughout the soil is not accomplished. Various types of lime spreaders are on the market and it is often possible for the farmer to devise home-manufactured machines for this purpose that are satisfactory. Spreaders may be used for ground limestone, hydrated lime, or burned lime after slaking. The practice of placing burned lime in piles in the field and slaking it by the addition of water or allowing it to slake in the air and then spreading by hand is a somewhat common one. Apart from the disagreeable features of this method the objections to it are that uniform distribution is difficult to accomplish and the slaking in a pile sometimes has an injurious effect on the soil immediately beneath the pile.

Whether lime should be applied before plowing or after plowing, and then harrowed in, as well as the time and manner of applying to growing crops where that can be done, are matters that must be decided in each individual case according to conditions and results sought to be accomplished. Probably application after plowing, followed by harrowing, is the most general and satisfactory practice. One important point in connection with the application of lime is the desirability of having the lime as thoroughly and uniformly distributed through the soil as possible.

Quantity.—The quantity to be applied naturally depends on the needs of the soil, on the form of lime used, the climatic conditions, and time of application. Applications of burned lime are usually from one-half a ton upward, or the equivalent, of carbonate of lime, although beneficial results frequently may be obtained by the use of smaller quantities. The conditions that make liming necessary, when corrected, tend to recur again after a time, the length of which depends on the soil and the treatment it receives. This makes it necessary to repeat the liming from time to time.

The question whether a large application once in several years is preferable to smaller applications more frequently, is one regarding which no general rule can be made. Arguments can be presented in favor of each procedure, and it is a matter where experiment and experience must decide.

Loss by leaching.—The leaching of lime from a soil, resulting in loss of valuable material, is a matter that should receive consideration in the practice of liming. It has been stated that the finer a lime is pulverized the more effective it is or the more immediately does it react in the soil. This effectiveness depends on ready solubility and if very fine material be applied in excess of that which can be held in the soil in a difficult soluble form it will be leached from the soil and lost.

This loss by leaching is a factor operating particularly in light soils having little organic matter and where the drainage is apt to be excessive, and is especially large in the South where such soils predominate and where the mild climate and heavy rainfall bring about leaching throughout the year.

Green manure.—It is evident from statements already made that the practice of liming, carried on as it should be, stands in very close relation to that of growing green crops to be plowed in to furnish organic material to the soil, and while good results frequently follow the plowing in of green crops where no liming is practiced usually the benefit will be still greater if lime is applied to the soil.

Few farms produce enough manure to maintain the organic content of all the land at the point where it should be. The use of commercial fertilizers containing organic matter such as dried blood, tankage, or cottonseed meal contribute but small quantities of this material, so that the plowing in of green crops is the only other method of accomplishing this result.

Leguminous crops such as clovers and cowpeas are usually grown for this purpose, although nonlegumes such as rye are sometimes used. To grow clovers successfully the majority of soils must be limed.

SOIL ACIDITY.

Soil conditions that make liming desirable or necessary are in many cases matters of ordinary observation or experience, but the reasons for the demand of the soil for lime are frequently not apparent. This is particularly the case with regard to the reaction of the soil, whether or not it is acid.

Though it may be assumed that a soil high in organic matter is acid, and certain types of native vegetation indicate acid conditions, the great majority of cultivated soils that may be slightly acid do not indicate that fact in any way that is conclusive to the farmer.

Indicators of soil acidity.—Soils that contain large quantities of organic matter, such as peats or muck soils, if not intimately asso-

ciated with marl deposits, are usually acid; and practically all soils, even when the content of organic matter is low, are acid if the drainage is poor.

The character of the native forest or other vegetation often indicates an acid soil. Among such indicators may be mentioned the growth of blueberry and wintergreen bushes, the presence of chestnut or sassafras trees, or a scrubby growth of oak or jack pine. In cultivated fields the presence of weeds such as sorrel or growth of moss on the surface of the soil may indicate acidity, but generally in the case of cultivated soils that may be slightly acid some test must be applied to the soil.

Lime requirement.—Mention has been made of laboratory methods for determining the lime requirement of soils, and in this connection it should be remembered that lime requirement and acidity are not necessarily the same. In other words, a soil may have a high lime requirement and still not be strongly acid as judged by other tests. The lime requirement being the quantity of lime necessary to add to the soil to bring about an alkaline reaction, this high lime requirement in the absence of high acidity probably is due to what may be called the absorptive power of the soil for lime.

Not infrequently the lime requirement as obtained by a laboratory method is not in actual accord with the field experience, and it is safe to assume that the real test of the reliability of any laboratory method of determining lime requirement is whether or not it gives a requirement in fair agreement with actual farm practice.

A laboratory examination will frequently indicate whether or not it is advisable to use lime at all, and, in any case, it gives whatever information is obtainable much more quickly than a field test, but it can not be too strongly urged upon farmers that they should experiment with their own soil in the field.

A number of methods have been proposed for determining whether or not a soil is acid that do not require laboratory equipment or special training, but it does not appear that any of them is generally applicable to all conditions or gives reliable results, with the exception of the litmus-paper test.

The litmus-paper test.—Certain dyes have the property of changing color when brought in contact with acids or alkalies. Such dyes are known as indicators, and litmus is one commonly used in this way. Litmus when in contact with moisture and an alkali such as lime hydroxide turns blue; and if to the blue litmus thus formed a slight excess of acid be added over that required to combine with and neutralize the lime, the litmus turns red. Between the blue and red is a neutral point, a light purple shade.

Litmus paper is an absorbent paper saturated with red, blue, or neutral litmus, and this when properly prepared is sensitive to slight acidity or alkalinity—that is, blue litmus when moistened

will turn red on contact with an acid, and vice versa red litmus will turn blue on contact with an alkali, indicating on the one hand what is called an acid reaction and on the other an alkaline reaction.

Litmus paper is used in testing soils for acidity; and the test usually is made by moistening the soil to form a compact mud, making an opening in this, inserting a strip of blue litmus paper, closing the soil around it and allowing it to stand for a short time and then noting any change of color. Precaution should be taken to prevent contact of the moist litmus paper with the fingers.

A modification of this method of making the litmus-paper test that has some advantage, especially in the case of red-colored soils, is

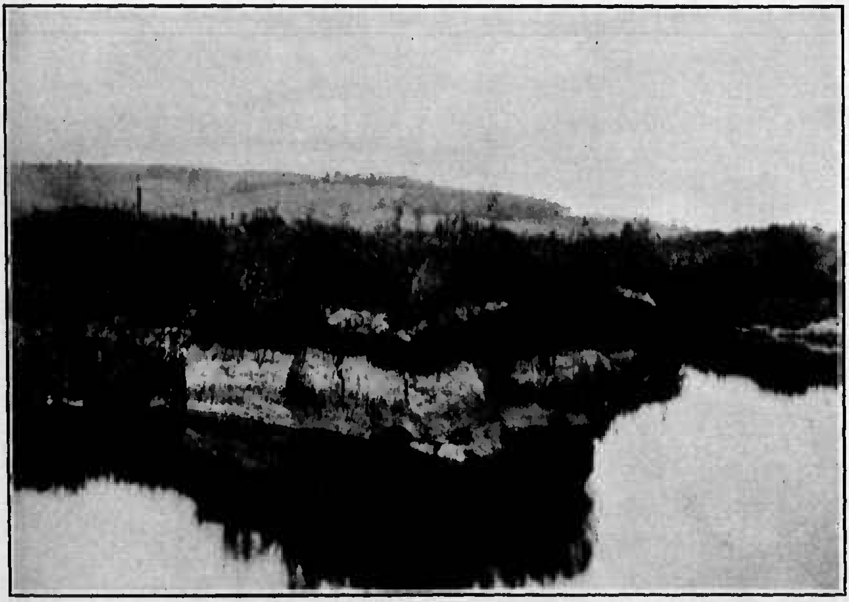


FIG. 3.—Valuable deposits of marl are found in many parts of the country and are convenient sources of lime.

as follows: The moistened strip of litmus paper is placed on the side or bottom of a glass or beaker and the dry soil then introduced into the glass, moistened thoroughly, and allowed to stand. Any change of color of the litmus paper can be observed through the glass and contamination of the paper with soil particles is prevented.

The interpretation of the change of color, if such occurs, is to some extent a matter of personal judgment and is most reliable when used by one of experience. The following points should be observed in using this test, and in drawing conclusions from it:

If the soil is dry it should be moistened and allowed to stand for a time before the test is applied.

If the soil effervesces on the application of dilute muriatic acid it probably contains more than half of 1 per cent of lime carbonate

and does not need liming, although it may show no alkaline reaction with red litmus. Frequently soils that do not effervesce are not in need of lime.

A mere bleaching of the blue color or leaching out by soil moisture should not be mistaken for a change to red. To prevent this as far as possible no more water should be used than is necessary to moisten the soil thoroughly.

Care should be taken that a mere staining of the surface of the paper by adhering grains of a red or reddish colored soil is not mistaken for a change of color of the paper.

The litmus-paper test, except in extreme cases, will not show difference in soil acidity.

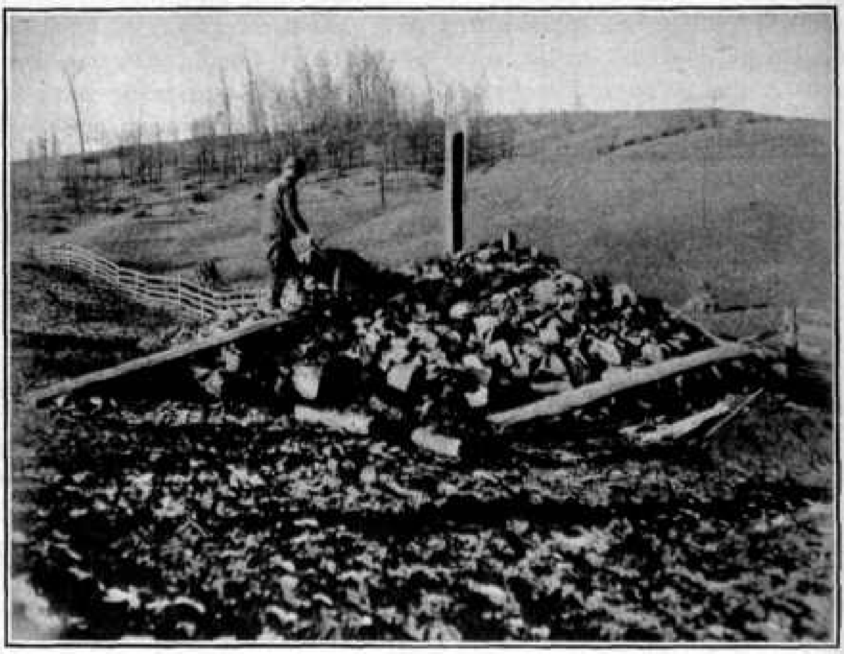


FIG. 4.—Making a lime kiln on a West Virginia farm.

A great many soils that do not show a strongly acid reaction with litmus paper have a high lime requirement, that is, they require an application of a considerable quantity of lime before they will show an alkaline reaction with red litmus paper and also respond in crop yield to liming.

LOCAL GRINDING OR BURNING.

If deposits of limestone are found on or near the farms on which it is desired to practice liming, the question of the desirability or profit of grinding or burning such material locally with farm labor presents itself.

In considering this matter it should be remembered that in the case of ground or pulverized limestone or of burned lime, the interest on the value of a limestone deposit is but a small part of the cost of such material when placed on the market. The chief items of cost of such material are labor, depreciation, the running of machinery or equipment, and fuel, and the chief advantage in having such a deposit near at hand is in the saving of freight and haulage.

It may be taken for granted that any farmer or community of farmers in attempting to use a local limestone supply will not turn out a product as efficiently as will a manufacturer with larger equipment and experience in the business, and that therefore the project

FIG. 5.—The kiln burning.

should receive careful consideration before undertaking. The ability to obtain material when wanted and the fact that the utilization of a local limestone deposit will render the farmers in the vicinity independent of freight congestion or other factors contributary to unsatisfactory delivery of liming material make the utilization of local limestone deposits a thing to be recommended in many localities. This is particularly true when local fuel is also available.

It should be pointed out in this connection, however, that portable crushers frequently do not grind as fine as is desirable, and such machines frequently deteriorate rather rapidly. Furthermore, prospective purchasers of portable crushers should not be satisfied with a

demonstration unless assured that the limestone with which the demonstration was made is as hard as that they propose to grind.

It is not likely that local lime burning can be profitably conducted by farmers except where a local fuel supply is available, and the general statements made regarding local grinding apply also to local lime burning.

In the case of both local grinding and crushing, limestone of lower grade can be made use of than could be used for the production of liming material commercially.

Where local marl deposits are available such material can be used profitably provided the cost of excavating or placing on the land is not too great.

In the utilization of local limestone or marl no expense should be incurred for machinery or equipment without first having the material it is proposed to use analyzed or examined by one competent to judge of its value for agricultural purposes.

WHAT SHOULD NOT BE EXPECTED OF LIMING.

Liming will not take the place of drainage. Acid-soil conditions frequently are due to poor drainage, but liming can improve only the conditions in the upper soil, making for better circulation of air and water. Impervious layers or hardpan should be broken up.

Liming can not take the place of proper crop rotation, cultivation, or soil management. In fact, the use of lime makes it more necessary that rotation and all cultural methods be studied more carefully.

Lime does not supply any of the elements furnished by fertilizers—potash, phosphoric acid, or nitrogen. The use of lime may enable the farmer to do with less fertilizer, or in an emergency to do without it altogether for a time.

Good results should not be expected from the application of lime to a soil deficient in organic matter, and liming should not be expected to build up such a soil unless such organic matter is supplied either in manure or green crops plowed in.

TERMS USED IN LIMING.

The following terms are used commonly in discussing the agricultural use of lime. The majority of these have appeared and been defined in the foregoing text, but for convenience are repeated here.

Weight of lime.—A Federal statute provides that in interstate shipment a large barrel of lime shall consist of 280 pounds and a small barrel 180 pounds net weight. The weight of a bushel of lime is fixed by law in several States and varies from 72 to 80 pounds.

Reaction.—A term applied to the behavior of a solution or a solid, when moist, when brought in contact with certain dyes called indicators. A solution or solid when moist that turns blue litmus red is said to have an acid reaction, and one

that turns red litmus blue an alkaline reaction. Slaked lime, or lime hydroxide, has an alkaline reaction.

Lime requirement.—The quantity of lime necessary to be added to a soil to produce a slight alkaline reaction. It is usually stated in pounds of lime per acre to the depth of 6 inches or other depth.

Fat or rich lime.—Sometimes called hot lime. Is lime made from limestone containing less than 10 per cent of impurities. On slaking it usually generates considerable heat.

Lean or poor lime.—Is made from limestone containing more than 10 per cent of impurities. It usually slakes slowly. Limestones ground for agricultural use frequently yield poor or lean lime on burning. The terms in this and the immediately preceding paragraph are used commonly in the building trade.

Magnesian or dolomitic lime.—Lime made from a limestone containing 10 to 15 per cent or more of magnesium carbonate.

Hydrated lime.—Trade name for slaked lime, or lime hydroxide, prepared by manufacture.

Carbonate of lime.—Lime oxide combined with carbonic acid. It occurs naturally as limestone, marl, oyster shell, coral, etc.

Oxide of lime.—Formed from carbonate by burning, whereby the carbonic acid is driven off. It does not occur in nature. It is known in trade as burned lime, quicklime, stone lime, caustic lime, or builder's lime.

Hydroxide of lime.—A combination of oxide of lime with water. It is also known as slaked lime or hydrated lime.

Agricultural lime.—A term originally applied to burned lime prepared for agricultural use, but now somewhat commonly applied to any form of lime intended for use in liming.

Liming.—The application of lime either in the form of carbonate or oxide to the soil.

Lime-oxide equivalent.—The proportion of oxide of lime in the carbonate or hydroxide. For pure material the ratio is approximately two parts of oxide (burned lime) are equal to three parts of hydroxide (slaked lime) or four parts of carbonate.

Sieves.—In grading ground or pulverized limestone or similar products, sieves of different-sized mesh or openings are used to separate the material into proportions of different grades of fineness. A 10-mesh sieve has 10 meshes to the running inch, or 100 meshes per square inch. A 60-mesh sieve has 3,600 meshes per square inch.

Organic matter.—Animal or vegetable material that has been left in or added to a soil. It includes material in all stages of decomposition from comparatively fresh material, the origin of which can be determined, to that thoroughly decomposed and in part, at least, combined with the mineral constituents of the soil.

Humus.—A term applied to the more or less dark colored, thoroughly decomposed organic material in a soil. It is known to be made up of a great variety of organic compounds, and the coloring material is frequently but a small part of the total humus.

Green manure.—A term applied to any crop grown for the purpose of being plowed in to replenish the supply of organic matter. Leguminous crops, such as the clovers and cowpeas, are grown most frequently for this purpose, but others, such as rye, are sometimes used.

PUBLICATIONS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE RELATING TO FERTILIZERS, THEIR RESOURCES, NATURE, AND APPLICATION TO SOILS.

AVAILABLE FOR FREE DISTRIBUTION BY THE DEPARTMENT.

Nitrogenous Fertilizers Obtainable in the United States. (Department Bulletin 37.)

Topographic Features of Desert Basins of the United States with Reference to Possible Occurrence of Potash. (Department Bulletin 54.)

Extension Course in Soils for Movable Schools of Agriculture. (Department Bulletin 355.)

Action of Manganese under Acid and Neutral Soil Conditions. (Department Bulletin 441.)

Organic Compounds and Fertilizer Action. (Soils Bulletin 77.)

Extraction of Potash from Silicate Rocks. (Soils Circular 71.)

Preparation of Fertilizer from Municipal Waste. (Separate 643, from Yearbook, 1914.)

Importance of Developing our Natural Resources of Potash. (Separate 717, from Yearbook, 1916.)

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

Commercial Fertilizers, Composition and Use. (Farmers' Bulletin 44.) Price, 5 cents.

The Liming of Soils. (Farmers' Bulletin 77.) Price, 5 cents.

Barnyard Manure. (Farmers' Bulletin 192.) Price, 5 cents.

Inorganic Composition of Some Important American Soils. (Department Bulletin 122.) Price, 5 cents.

Production and Fertilizer Value of Citric-soluble Phosphoric Acid and Potash. (Department Bulletin 143.) Price, 5 cents.

Utilization of Fish Waste of the Pacific Coast for Fertilizer. (Department Bulletin 150.) Price, 15 cents.

Nitrogen of Processed Fertilizers. (Department Bulletin 158.) Price, 5 cents.

Phosphate Rock and Methods Proposed for Its Utilization as Fertilizer. (Department Bulletin 312.) Price, 5 cents.

Recovery of Potash from Alunite. (Department Bulletin 415.) Price, 5 cents.

Certain Organic Constituents of Soils in Relation to Soil Fertility. (Soils Bulletin 47.) Price, 10 cents.

Fertility of Soils as Affected by Manures. (Soils Bulletin 48.) Price, 10 cents.

Fertilizers for Corn Soils. (Soils Bulletin 64.) Price, 5 cents.

Fertilizers for Potash Soils. (Soils Bulletin 65.) Price, 5 cents.

Fertilizers on Soils Used for Oats, Hay, and Miscellaneous Crops. (Soils Bulletin 67.) Price, 10 cents.

Chemical Nature of Soil Organic Matter. (Soils Bulletin 74.) Price, 10 cents.

A Review of the Phosphate Fields of Florida. (Soils Bulletin 76.) Price, 5 cents.

A Beneficial Organic Constituent of Soils: Creatinine. (Soils Bulletin 83.) Price, 10 cents.

Some Organic Soil Constituents. (Soils Bulletin 88.) Price, 10 cents.

The Utilization of Acid and Basic Slags in the Manufacture of Fertilizers. (Soils Bulletin 95.) Price, 5 cents.

City Street Sweepings as Fertilizer. (Soils Circular 66.) Price, 5 cents.

Alunite and Kelp as Potash Fertilizers. (Soils Circular 76.) Price, 5 cents.

The Use of Feldspathic Rocks as Fertilizers. (Plant Industry Bulletin 104.) Price, 5 cents.